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PATENT AND TRADEMARK OFFICEATTORNEY'S DOCKET NUMBER  
10191/1109**TRANSMITTAL LETTER TO THE UNITED STATES  
DESIGNATED/ELECTED OFFICE (DO/EO/US)  
CONCERNING A FILING UNDER 35 U.S.C. 371**

U.S. APPLICATION NO. (If known, see 37 CFR 1.5)

**09/367027**INTERNATIONAL APPLICATION NO.  
PCT/DE98/00192INTERNATIONAL FILING DATE  
(22.01.98)  
22 January 1998PRIORITY DATE CLAIMED:  
(07.02.97)  
7 February 1997TITLE OF INVENTION  
**MULTIPIXEL LIQUID CRYSTAL DISPLAY**APPLICANT(S) FOR DO/EO/US  
**HEINMUELLER, Christina; and HAAS, Gunther**

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f)) immediately rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
  - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
  - b. ☒ has been transmitted by the International Bureau.
  - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
  - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
  - b. ☐ have been transmitted by the International Bureau.
  - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
  - d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). (unsigned)
10. ☒ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

**Items 11. to 16. below concern other document(s) or information included:**

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A **FIRST** preliminary amendment.  
☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
14. ☐ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information: International Search Report; Preliminary Examination Report; PCT/RO/101, and Return Receipt Postcard.

EXPRESS MAIL NO.:

82179955509US

U.S. APPLICATION NO. 09/367027  
37 C.F.R. 1.5

INTERNATIONAL APPLICATION NO.  
PCT/DE98/00192

ATTORNEY'S DOCKET NUMBER  
10191/1109

☒ The following fees are submitted:

**Basic National Fee (37 CFR 1.492(a)(1)-(5)):**

Search Report has been prepared by the EUROPEAN PATENT OFFICE or  
JPO ..... \$840.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) ..... \$670.00

No international preliminary examination fee paid to USPTO (37 CFR 1.482) but  
international search fee paid to USPTO (37 CFR 1.445(a)(2)) ..... \$750.00

Neither international preliminary examination fee (37 CFR 1.482) nor international  
search fee (37 CFR 1.445(a)(2)) paid to USPTO ..... \$970.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims  
satisfied provisions of PCT Article 33(2)-(4) ..... \$96.00

CALCULATIONS | PTO USE ONLY

ENTER APPROPRIATE BASIC FEE AMOUNT = \$840

Surcharge of \$130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months  
from the earliest claimed priority date (37 CFR 1.492(e)). \$

Claims	Number Filed	Number Extra	Rate	
Total Claims	19 - 20 =	0	X \$18.00	\$ 0
Independent Claims	1 - 3 =	0	X \$78.00	\$ 0
Multiple dependent claim(s) (if applicable)			+ \$260.00	\$

TOTAL OF ABOVE CALCULATIONS = \$ 840

Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity statement must  
also be filed. (Note 37 CFR 1.9, 1.27, 1.28). \$

SUBTOTAL = \$ 840

Processing fee of \$130.00 for furnishing the English translation later the ☐ 20 ☐ 30  
months from the earliest claimed priority date (37 CFR 1.492(f)). + \$

TOTAL NATIONAL FEE = \$ 840

Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be  
accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property + \$

TOTAL FEES ENCLOSED = \$ 840

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refunded	\$
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- a. ☐ A check in the amount of \$\_\_\_\_\_ to cover the above fees is enclosed.
- b. ☒ Please charge my Deposit Account No. 11-0600 in the amount of **\$840.00** to cover the above fees. A duplicate copy of this sheet is enclosed.
- c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 11-0600. A duplicate copy of this sheet is enclosed.

**NOTE:** Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

Kenyon & Kenyon  
One Broadway  
New York, New York 10004

SIGNATURE

Richard L. Mayer, Reg. No. 22,490  
NAME

DATE

8/6/99

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

Inventor(s) : HEINMUELLER et al.  
Serial No. : To Be Assigned  
Filed : Herewith  
For : MULTIPixel LIQUID CRYSTAL DISPLAY  
Examiner : To Be Assigned  
Art Unit : To Be Assigned

Assistant Commissioner  
for Patents  
Washington, D.C. 20231

**PRELIMINARY AMENDMENT**

SIR:

Kindly amend the above-identified application before examination, as set forth below.

**IN THE SPECIFICATION:**

On page 1, before line 3, insert:

--FIELD OF THE INVENTION--.

On page 1, line 3, before "invention", insert --present--.

On page 1, line 4, delete "according to the preamble of Claim 1".

On page 1, delete line 6, and insert:

--BACKGROUND INFORMATION--.

On page 1, line 16, delete ",".

On page 1, line 17, delete "helically twisted by 90°,".

On page 1, line 18, after "substrates", insert --helically twisted by 90°--.

On page 1, line 19, change "Figure 3" to --Figures 3a and 3b--.

On page 2, line 25, change "Application 646 829 A1" to --Application No. 646 829--.

On page 3, line 15, change "method" to --Twisted Nematic and Tilted Homeotropic Liquid Crystal Displays for Active Matrix Applications--.

On page 3, line 19, change "Application 646 829 A1" to --Application No. 646 829--.

On page 4, before line 1, insert:

--SUMMARY OF THE INVENTION--.

On page 4, line 1, change "The" to --An--.

On page 4, line 1, before "invention" insert --present--.

On page 4, delete lines 5-8.

On page 4, line 10, before "invention" insert --present--.

On page 4, line 13, before "invention" insert --present--.

On page 5, line 21, change " $-200 \text{ nm} < (n_z - n_o)$ " to --  $-200 \text{ nm} < (n_z - n_o) \cdot d$ --.

On page 6, line 4, change "liquid crystal pixel" to --pixel of the liquid crystal--.

On page 6, line 5, after "another" insert --to a viewing angle range having a higher-order symmetry--.

On page 7, delete lines 10-31, and on page 8, delete lines 1-22,  
and in their place insert:

--BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows an exemplary embodiment of a liquid crystal display according to the present invention.

Figure 2 shows an alignment of indices of refraction in a retardation film according to the present invention having two optical axes.

Figure 3a shows a conventional twisted nematic liquid crystal display.

Figure 3b shows another conventional twisted nematic liquid crystal display.

Figure 4 shows a model for representing coordinates for determining the viewing angle.

Figure 5 shows dependence of contrast and gray scale level on the viewing angle in a conventional nematic liquid crystal display.

Figure 6a shows a variation of transmission as a function of an angle of inclination  $\theta$  for different gray scale settings.

Figure 6b shows another variation of transmission as a function of the angle of inclination  $\theta$  for different gray scale settings.

Figure 7 shows an orientation of the liquid crystal edge molecules for a pixel divided into two subpixels.

Figure 8 shows the dependence of contrast and gray scale inversion on the viewing angle for one orientation of the liquid crystal molecules according to Figure 7 without retardation film.

Figure 9 shows the dependence of contrast and gray scale inversion for an arrangement according to Figure 7 with a biaxial retardation film according to the present invention.

Figure 10 shows the orientation of the liquid crystal edge molecules on the base substrate and the cover substrate with the pixel being divided into four subpixels.

Figure 11 shows the diagram for Figure 10 for the dependence of contrast and gray scale inversion on the viewing angle without a retardation film.

Figure 12 shows the diagram for Figure 10 for the dependence of contrast and gray scale inversion on the viewing angle with the optically biaxial retardation film according to the present invention.

**DETAILED DESCRIPTION--.**

On page 8, line 24, change "in the preamble of the description" to --above--.

**IN THE ABSTRACT:**

Delete line 1, and insert:

**--ABSTRACT OF THE DISCLOSURE--.**

Line 4, delete "(P1, P2)".

Line 5, delete "(DS, GS)".

Line 8, delete ", according to the present invention,".

Line 10, delete "(V1, V2)".

**IN THE CLAIMS:**

On page 11, line 1, change "Patent Claims" to --WHAT IS CLAIMED IS:--.

Please cancel original claims 1-19 and cancel substitute claims 1-4 without prejudice, and add new claims 20-38, as follows:

--20. (New) A liquid crystal display, comprising:

- a plurality of pixels subdivided into a plurality of subpixels
- a liquid crystal cell having a top surface and a bottom surface, and including:
  - a first substrate provided with a transparent electrode,
  - a second substrate provided with another transparent electrode, and
  - a liquid crystal including liquid crystal molecules and arranged between the first substrate and the second substrate, wherein the liquid crystal exhibits a different orientation for each one of the plurality of subpixels;
- a first polarizer arranged on the top surface of the liquid crystal cell;
- a second polarizer arranged on the bottom surface of the liquid crystal cell; and
- an optically biaxial retardation film associated with a plurality of different retraction indices and provided at least between one of the first polarizer and the second polarizer and the liquid crystal in order to compensate for a dependence of optical characteristics including a transmission on a viewing angle and a contrast on the viewing angle, wherein the plurality of different refraction indexes includes at least:
  - a first retraction index  $n_z$  occurring along an axis that is essentially parallel to a normal to the liquid crystal cell in the retardation film, and
  - a second refraction index  $n_e$  occurring along an axis that is essentially perpendicular to an orientation of the liquid crystal molecules with respect to a corresponding adjacent one of the first substrate and the second substrate in the retardation film.

21. (New) The liquid crystal display according to claim 20, wherein the plurality of different refraction indexes includes a third refraction index  $n_o$ , and wherein the retardation film has the following characteristics:

$$n_e - n_o > 0 \text{ and}$$

$$n_z - n_o < 0.$$

22. (New) The liquid crystal display according to claim 20, wherein the retardation film is arranged on the liquid crystal cell between the liquid crystal cell and one of the first polarizer and the second polarizer.

23. (New) The liquid crystal cell according to claim 20, wherein the retardation film is arranged in the liquid crystal cell between the liquid crystal and one of the first substrate and the second substrate.

24. (New) The liquid crystal cell according to claim 20, wherein the retardation film is arranged on each one of the top surface and the bottom surface of the liquid crystal cell between the liquid crystal and the first polarizer and the second polarizer.

25. (New) The liquid crystal display according to claim 20, wherein the plurality of different refraction indexes includes a third refraction index  $n_0$ , and wherein when the retardation film is arranged on each one of the top surface and the bottom surface of the liquid crystal cell, the retardation film exhibits the following characteristics:

$$70 \text{ nm} < (n_e - n_0) \cdot d < 200 \text{ nm}, \text{ and}$$

$$-200 \text{ nm} < (n_z - n_0) \cdot d < 0,$$

where  $d$  is a thickness of the retardation film.

26. (New) The liquid crystal display according to claim 25, wherein when the retardation film is arranged on one of the top surface and the bottom surface of the liquid crystal cell, the retardation film exhibits the following characteristics:

$$70 \text{ nm} < (n_e - n_0) \cdot d < 200 \text{ nm} \text{ and}$$

$$-200 \text{ nm} < (n_z - n_0) \cdot d < 0.$$

27. (New) The liquid crystal display according to claim 20, wherein the retardation film includes at least one plastic film.

28. (New) The liquid crystal display according to claim 27, wherein the at least one plastic film includes a unidirectional plastic film which is not stretched to saturation.



29. (New) The liquid crystal display according to claim 27, wherein the at least one plastic film includes a plastic film which is stretched bidirectionally.

30. (New) The liquid crystal display according to claim 27, wherein the retardation film includes a combination of at least one uniaxially positive film and at least one uniaxially negative film.

31. (New) The liquid crystal display according to claim 20, wherein the retardation film includes a holographic element.

32. (New) The liquid crystal display according to claim 20, wherein the retardation film includes a liquid crystal polymer.

33. (New) The liquid crystal display according to claim 20, wherein the liquid crystal is arranged according to the different orientation for each one of the plurality of subpixels corresponding to one of the plurality of pixels such that a viewing angle range of each one of the plurality of pixel supplements each other to form an essentially point-symmetric viewing angle range.

34. (New) The liquid crystal display according to claim 20, wherein the liquid crystal cell includes a TN cell which is twisted between 80° and 100°.

35. (New) The liquid crystal display according to claim 20, further comprising:  
a photosensitive layer for orienting the liquid crystal molecules in a particular direction on surfaces of the first substrate and the second substrate, the particular direction of the liquid crystal molecules being determined by an exposure to a light.

36. (New) The liquid crystal display according to claim 20, wherein boundary areas between the plurality of subpixels are covered by a mask.

37. (New) The liquid crystal display according to claim 20, wherein each one of the plurality of pixels includes a switching element.

38. (New) The liquid crystal display according to claim 36, wherein each one of the plurality of pixels includes a thin-layer transistor and a reservoir capacitor, at least one electrode of the reservoir capacitor including a conductive, non-transparent layer which covers the boundary areas between the plurality of subpixels.--.

### Remarks

This Preliminary Amendment cancels, without prejudice, original claims 1-19 and cancels substitute claims 1-4 in the underlying PCT Application No. PCT/DE98/00192 and adds new claims 20-38. The new claims conform the claims to U.S. Patent and Trademark Office rules and do not add new matter to the application.

The above amendments to the specification and abstract are to conform the specification and abstract to U.S. Patent and Trademark Office rules, and do not introduce new matter into the application.

The underlying PCT Application No. PCT/DE98/00192 includes an International Search Report, dated June 17, 1998. The Search Report includes a list of documents that were uncovered in the underlying PCT Application. A copy of the Search Report is included herewith.

The underlying PCT Application also includes an International Preliminary Examination Report, dated April 22, 1999, a copy of which is included herewith.

Applicants assert that the subject matter of the present application is new, non-obvious, and useful. Prompt consideration and allowance of the application are respectfully requested.

Respectfully submitted,

Dated: 8/6/99

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[10191/1109]

## MULTIPIXEL LIQUID CRYSTAL DISPLAY

The invention relates to a multipixel liquid crystal display having a liquid crystal cell and polarizers according to the preamble of Claim 1.

## Background Information

Liquid crystal displays have become known in different embodiments. STN and TN liquid crystals are most frequently used. STN stands for Super Twisted Nematic and TN stands for Twisted Nematic.

Twisted Nematic means that a twisted nematic liquid crystal phase is used.

The design of a conventional TN display is illustrated in Figures 3a and 3b. A liquid crystal is sandwiched between two glass plates, each of which is coated with a transparent electrode. The liquid crystal molecules are indicated as elongated rods. The liquid crystal molecules are, oriented helically twisted by  $90^\circ$ , using an orientation layer, so that they are arranged between the substrates. Polarization filters, whose preferred direction of transmission is indicated by a double arrow in Figure 3, are applied to the outside of the glass plates. The polarizer is located on the side of incidence of light, and the analyzer is located on the side where the light exits. In the voltage-free state of the cell illustrated in Figure 3a, polarized light enters, is twisted by  $90^\circ$  due to the  $90^\circ$  liquid crystal molecule helix and can exit through the analyzer. Liquid crystal displays that are transparent in the voltage-free state are known as "normally white" displays. If a sufficiently high voltage is applied between the electrodes, the liquid crystal molecules align themselves parallel to the electric field, whereby the incident light remains essentially unaffected and is therefore absorbed by the analyzer. In this state the liquid crystal display is dark. In a normally white display, light transmission decreases continuously with increasing voltage. Thus a certain transmission and therefore a gray value (gray level) can be uniquely assigned to a given voltage. In conventional liquid crystal displays, however, transmission and thus the gray level are dependent on the viewing angle. The viewing angle can be uniquely represented using polar coordinates as Figure 4 shows.

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Thus angle  $\varphi$  in the plane of the display assumes values from 0 to 360°. Angle  $\theta$  has a range of values from 0 to a maximum of 90° and shows to what degree the viewing angle is inclined in relation to the normal to the liquid crystal display. Figure 6a shows transmission as a function of inclination angle  $\theta$  for  $\varphi = 0^\circ$  and four different gray levels from g1 to g4.

Even at  $\varphi = \pm 27^\circ$ ,  $T(g4) > T(g3)$ . This means that at this point an undesirable gray level inversion exists. Fig. 6b shows transmission  $T$  as a function of inclination angle  $\theta$  for  $\varphi = 90^\circ$ . Here a gray level inversion occurs at an angle as small as  $\theta > 12^\circ$ . Like the gray levels, the contrast of the liquid crystal display is also a function of  $\theta$  and  $\varphi$ . It is defined as the ratio between the highest and the lowest transmission. Like in the evaluation of gray level inversion, a range of  $\theta$  can be found for every  $\varphi$  where the contrast is greater than a minimum contrast.

The conoscope diagram (see Fig. 5) illustrates functions  $\theta$  and  $\varphi$ . Here inclination angle  $\theta$  and angle  $\varphi$  are represented on a circle, where  $\theta$  is the radial component and  $\varphi$  is the azimuth. Both the results of the gray level inversion and the contrast values can be plotted in this diagram. A range (cross hatched area in Fig. 5) in which the contrast does not drop below a minimum value (see cross-wise shaded area in Fig. 5) and also where there is no gray level inversion (see Fig. 5, lengthwise shaded area) is defined as a suitable viewing angle range. The boundary line of the contrast area is known as the ISO contrast curve. As Fig. 5 shows, a conventional TN liquid crystal display without any special features has only a very narrow suitable viewing angle range (cross hatched area).

In order to increase this range, different methods can presently be used.

In European Patent Application 646 829 A1, the use of a compensation layer is proposed to enlarge the viewing angle range. This layer includes, as an essential component, a discotic retardation film made from a discotic liquid crystal. This is an optically uniaxial film, the regular refraction index  $n_o$  being greater than the special refraction index  $n_e$ . Therefore, the delay  $V_R = d_R \cdot (n_e - n_o)$  is negative ( $d_R$  being the film thickness). The absolute value of the delay of this film is equal to the delay of the liquid crystal layer, but it has the opposite sign. With the retardation film described in the aforementioned patent application, in addition to

compensating for the birefringence of the material in the liquid crystal, the birefringence caused by the liquid crystal edge molecules on the substrate surface of the liquid crystal cell, which have a certain pre-tilt with respect to the substrate surface, is compensated for. The discotic retardation film must always be adjusted to the orientation of the liquid crystals for a desired compensation effect. If such a film is applied between the cell and the polarization filter, the suitable viewing angle range can be substantially improved.

Another option for improving the suitable viewing angle range is to equalize the asymmetry in the dependence of the contrast on the viewing angle with respect to the dependence of the gray level inversion (see Fig. 5) on the viewing angle. This asymmetry arises due to the asymmetric orientation of the liquid crystal molecules. One method to obtain a symmetric viewing angle range of the liquid crystal cell is to split each pixel into two subpixels having opposite orientations of the liquid crystal molecules, so that the viewing angle range of the first subpixel is rotated with respect to that of the second subpixel by  $180^\circ$  (Fig. 7, Two-domain method, K.H. Yang: Record 1991 Int. Display Res. Conf., San Diego, California). Thus the asymmetric viewing angle ranges of the subpixels supplement each other to form a relatively small, however, essentially point-symmetric viewing angle range (see Fig. 8). An additional increase in this viewing angle range using a compensation film, as disclosed in European Patent Application 646 829 A1 is not feasible, since the discotic layer is adjusted to a certain orientation of the liquid crystal and thus only one subpixel can be compensated for at a time.

An alternative option is to subdivide a pixel into four subpixels (4-domain method). In this case, each subpixel has a different orientation in that, for example, on a substrate side with diagonally adjacent subpixel ranges, the liquid crystal edge molecules are oriented with a  $180^\circ$  offset (see Fig. 10). The technological complexity using the 4-domain method is considerably higher than with the 2-domain method; however, a relatively larger suitable viewing angle range is achieved (see Fig. 11).

Also with this method, no improvement occurs in the suitable viewing angle range due to the above-described compensation layer for the reasons presented previously.

The object of the invention is to provide a liquid crystal display having as large a viewing angle range as possible, in which no gray level inversion takes place and the contrast is greater than a minimum value (e.g., 10).

5 This object is achieved by the features of Claim 1.

Advantageous and suitable refinements of the liquid crystal display according to the present invention are presented in the subclaims.

10 The invention is based on a liquid crystal display having a plurality of pixels, which includes a liquid crystal cell and polarizers that are arranged on the top and bottom of the liquid crystal cell, the liquid crystal cell including two substrates with transparent electrodes and a liquid crystal sandwiched therebetween. The core of the invention is that each pixel is subdivided into at least two subpixels, in which the liquid crystal has different orientations and that an  
15 optically biaxial retardation film with different refraction indices  $n_e$ ,  $n_o$ ,  $n_z$  is provided at least between a polarizer and the liquid crystal in order to compensate for the dependence of the optical properties of the liquid crystal display, such as, for example, transmission and contrast, on the viewing angle, the refraction index  $n_z$  being measured in the retardation film along an axis that is essentially parallel to the normal to the liquid crystal cell. Thus the  
20 advantages of a multidomain method can be combined with those of a layer that compensates for the birefringence in the liquid crystal cell. In particular, due to the optical biaxiality, the refraction characteristics of the liquid crystal molecules opposite the substrate surface in the liquid crystal cell can be compensated for as desired, in particular, achieving an especially effective compensation. While the basic orientation of the liquid crystal molecules should be  
25 taken into account, an orientation of the liquid crystal molecules offset by  $180^\circ$  is, however, allowable, which ultimately allows the use of a retardation film for differently oriented subpixels. In addition, the retardation film according to the present invention, in combination with the multidomain method, in particular when the liquid crystal molecules are oriented due to the exposure of a photosensitive layer, represents a cost-effective alternative to relatively  
30 similarly effective compensation layers (e.g., discotic retardation films).

In order to achieve a particularly effective compensation of the viewing angle dependencies, it is furthermore proposed that the refraction indices  $n_e$ ,  $n_o$ ,  $n_z$  of the biaxial retardation film be dimensioned so that  $n_e - n_o > 0$  and  $n_z - n_o < 0$ .

5 In order to achieve a relatively simple design of the liquid crystal display, it is furthermore proposed that the retardation film be arranged on the liquid crystal cell between the polarizer and the liquid crystal cell.

10 For a particularly compact design it is advantageous if the retardation film in the liquid crystal cell is arranged between the liquid crystal and the substrate.

A particularly simple and compact design is achieved when the substrate itself forms the retardation film (plastic substrate with a suitable delay).

5 In order to provide a high degree of symmetry, it is also proposed that the retardation film be arranged on both sides between the liquid crystal and the polarizers.

For a retardation film applied on both sides, it is advantageous if the layer meets the following dimensioning specifications:

20  $70 \text{ nm} < (n_e - n_o) \cdot d < 200 \text{ nm}$  and  $-200 \text{ nm} < (n_z - n_o)$ , where  $d$  is the thickness of the retardation film. If the retardation film is only on one side, basically the same values given in nm can be used without any considerable deterioration in the compensation effect.

25 In a particularly advantageous embodiment, one or more plastic films are used as the retardation film. For example, a retardation film made of a unidirectional plastic film can be used, which however, is not stretched to saturation. The use of a retardation film made of a bidirectionally stretched plastic film is also possible. Finally, a combination of one or more uniaxially positive and one or more uniaxially negative films is also possible. Retardation  
30 films have the advantage that they can be applied in a simple manner, for example, by laminating.

The retardation film can also be implemented using a holographic element or in the form of a liquid crystal polymer.

It is particularly advantageous if the subpixels of a liquid crystal pixel are oriented so that the viewing angle ranges of the individual subpixels supplement one another. For a TN liquid crystal cell with pixels subdivided into two subpixels, this can be implemented by the angles of the liquid crystal edge molecules of the subpixels on the base substrate being of opposite orientations;

the angles of the liquid crystal edge molecules of the subpixels on the cover substrate being of opposite orientations;

the angles of the liquid crystal edge molecules of the subpixels on both substrates being of opposite orientations;

the angles of orientation of the liquid crystal edge molecules of the subpixels on the base substrate being of different magnitudes;

the angles of orientation of the liquid crystal edge molecules of the subpixels on the cover substrate being of different magnitudes; or

the angles of orientation of the liquid crystal edge molecules of the subpixels on the base and cover substrates being of different magnitudes.

The twist of the TN cells may amount to between  $80^\circ$  and  $100^\circ$ .

The liquid crystal molecules on the substrate surfaces can be orientated by mechanical rubbing or via an orientation layer.

In a particularly preferred embodiment, a photosensitive film is used to orient the liquid crystal molecules on the substrate surfaces; the preferential direction of orientation of the liquid crystal molecules is determined by exposure to light.

In order to achieve a high contrast, it is also proposed that the boundary areas between the subpixels be covered by a mask.



In an advantageous embodiment, each pixel has a switch element such as a thin-layer transistor, a thin-layer diode or a metal-insulator-metal-diode.

In another advantageous embodiment, a thin-layer transistor and a reservoir capacitor is arranged in each pixel; at least one electrode of the reservoir capacitor is implemented using a conductive, non-transparent layer, which covers the boundary area between the subpixels. In this manner, the boundary area between the pixels is covered while the aperture of the liquid crystal display remains constant.

## Brief Description of the Drawings

Different embodiments of the present invention are illustrated in the drawings and described in detail in the description that follows.

Figure 1 schematically shows the design of a liquid crystal display according to the present invention;

Figure 2 shows the alignment of the indices of refraction in a retardation film according to the present invention having two optical axes;

Figures 3a, b schematically show the design of a conventional twisted nematic liquid crystal display;

Figure 4 shows a model for representing the coordinates for determining the viewing angle;

Figure 5 illustrates the dependence of contrast and gray scale level on the viewing angle in a conventional nematic liquid crystal display;

Figures 6a, b show the variation of transmission as a function of the angle of inclination  $\theta$  for different gray scale settings;

Figure 7 schematically shows the orientation of the liquid crystal edge molecules for a pixel divided into two subpixels;

Figure 8 shows the dependence of contrast and gray scale inversion on the viewing angle for one orientation of the liquid crystal molecules according to Fig. 7 without retardation film;

Figure 9 shows the dependence of contrast and gray scale inversion for an arrangement according to Fig. 7 with a biaxial retardation film according to the present invention;

Figure 10 shows the orientation of the liquid crystal edge molecules on the base substrate and the cover substrate with the pixel being divided into four subpixels;

Figure 11 shows the diagram for Fig. 10 for the dependence of contrast and gray scale inversion on the viewing angle without a retardation film; and

Figure 12 shows the diagram for Fig. 10 for the dependence of contrast and gray scale inversion on the viewing angle with the optically biaxial retardation film according to the present invention.

#### Detailed Description

As mentioned in the preamble of the description, the embodiments are described on the basis of a conventional twisted nematic liquid crystal display according to Figs. 3a and 3b. A liquid crystal, twisted by  $90^\circ$ , is sandwiched between glass substrates 1, 2; its elongated liquid crystal molecules are represented by rods 3. A polarizer 4, 5 is mounted on each glass substrate. The transmission direction of the polarizers (indicated by a double arrow) is the same as the orientation of the longitudinal axis of the liquid crystal molecules, but it may also be oriented  $90^\circ$  to that direction. Fig. 3a shows the no-voltage state in which the penetrating light (indicated by the wide arrow) is twisted by  $90^\circ$  due to the liquid crystal helix and then

can exit polarizer 5 unimpeded. The cell is transparent and appears light-colored. When a voltage is applied, the liquid crystal molecules become oriented by their dielectric anisotropy in the electric field, whereby the light (represented by a wide arrow in Fig. 3b) penetrating from below passes through the liquid crystal cell unimpeded and is then absorbed by polarizer 5. In this state, the liquid crystal cell appears dark-colored.

One undesired liquid crystal cell effect is dependence, in particular, of gray levels and contrast on the viewing angle. To determine the viewing angle, the coordinates shown in Fig. 4 are introduced. Angle  $\phi$  located in the plane of the substrate, may vary from  $0^\circ$  to  $360^\circ$ , while angle  $\theta$  measures the inclination with respect to the normal to the liquid crystal (z). For Figs. 5, 6a and 6b, reference is made to the preamble to the description. Subject to improvement is the cross hatched area of a conventional TN cell, which can be considered a suitable viewing angle range.

For this purpose, a liquid crystal display designed according to the present invention according to Fig. 1 is used. A liquid crystal is placed between a base substrate (GS) and a cover substrate (DS); the longitudinal axes of its liquid crystal edge molecules are oriented according to the arrows on the base and cover substrate. A retardation film V1, V2 is arranged on the top and bottom of the base and cover substrates. The extraordinary axis ( $n_e$ ) in the retardation film is denoted by arrows; it extends perpendicular to the orientation of the liquid crystal molecules on the corresponding adjacent substrate (see Fig. 2 for the position of the other optical axes in the retardation film). Finally, a polarization filter P1 and P2 is installed on retardation films V1 and V2, respectively; the absorbing axes of these filters are parallel to the orientation of the liquid crystal molecules for the corresponding adjacent substrate (broken-line double arrow). In addition to a strong perpendicular or parallel orientation between the given directions, the projection of the extraordinary axis of the liquid crystal edge molecules may form an angle from  $0^\circ$  to  $5^\circ$  with the absorbing axis of the polarizer for the base and cover substrate, and the extraordinary axis of the retardation film may form an angle of  $85^\circ$  to  $90^\circ$  with the absorbing axis of the polarizer.

According to the present invention, a pixel is to be divided into subpixels according to Fig. 7

with adjacent subpixels 6, 7 being oriented in  $180^\circ$  opposite directions as shown by the symbolic representation of longitudinal axis 8 of the molecules. Such an orientation results in an essentially point-symmetric variation of the gray level inversion and the border line for a surface in which the contrast does not drop below a minimum (see Fig. 8). The area in which no gray level inversion occurs is represented in Fig. 8 by crosses, while the isocontrast curve for a minimum contrast of 10 is represented by squares.

The individual areas, but especially the section area where the contrast does not drop below a minimum value and no gray level inversion occurs are considerably increased by the additional use of a retardation film according to the present invention (see Fig. 9).

An even better initial situation with regard to the dependence of contrast and gray level inversion on the viewing angle is achieved by dividing a pixel into four subpixels according to Fig. 10. As a result of the orientation of longitudinal axes 8 of the molecules as illustrated in Fig. 10, different liquid crystal orientations are obtained for all four subpixels. The symmetry and dependence on the viewing angle are thus improved, but especially the section surface in which the contrast does not drop below a minimum and no gray level inversion occurs is considerably enlarged. If the retardation film with two optical axes according to the present invention is also used, an even more improved contrast and gray level inversion situation is achieved, as shown in the diagram of Fig. 12. Up to an inclination angle  $\theta$  of approximately  $65^\circ$ , the contrast at no point drops below a minimum, which is 10 in this embodiment. Also, up to an inclination angle  $\theta$  of approximately  $65^\circ$ , no gray level inversion takes place.

The biaxial retardation film thus makes it possible to manufacture liquid crystal displays that allow excellent viewing angle dependence by the additional use of the "multidomain method."

## Patent Claims

1. Liquid crystal display with a plurality of pixels, having a liquid crystal cell and polarizers (4,5), which are arranged on the top and bottom of the liquid crystal cell, the liquid crystal cell having two substrates (1, 2) with transparent electrodes and a liquid crystal (3) sandwiched therebetween, characterized in that each pixel is subdivided into at least two subpixels (6, 7), in which the liquid crystal has different orientations, and an optically biaxial retardation film (V1, V2) with different refraction indices  $n_e$ ,  $n_0$ ,  $n_z$  is provided between a polarizer (4, 5) and the liquid crystal (3) to compensate for the dependence of the optical characteristics of the liquid crystal display such as transmission and contrast on the viewing angle, the refraction index  $n_z$  occurring along an axis that is essentially parallel to the normal to the liquid crystal cell in the retardation film.
2. Liquid crystal display according to Claim 1, characterized in that for the refraction indices  $n_e$ ,  $n_0$ ,  $n_z$  of the biaxial retardation film,  $n_e - n_0 > 0$  and  $n_z - n_0 < 0$ .
3. Liquid crystal display according to one of the foregoing claims, characterized in that the retardation film is arranged on the liquid crystal cell between the polarizer (4, 5) and the liquid crystal cell.
4. Liquid crystal cell according to one of the foregoing claims, characterized in that the retardation film is arranged in the liquid crystal cell between the liquid crystal (3) and the substrate (1, 2).
5. Liquid crystal cell according to one of the foregoing claims, characterized in that the retardation film is arranged on both sides between the liquid crystal (3) and the polarizers (4, 5).
6. Liquid crystal display according to one of the foregoing claims, characterized in that, in a retardation film arranged on both sides, the retardation film has the following characteristics :  $70 \text{ nm} < (n_e - n_0) \cdot d < 200 \text{ nm}$  and  $-200 \text{ nm} < (n_z - n_0) \cdot d < 0$ , where  $d$  is the

thickness of the retardation film.

7. Liquid crystal display according to Claim 6, characterized in that, for a retardation film applied on one side, the values given in nanometers remain essentially unchanged.

8. Liquid crystal display according to one of the foregoing claims, characterized in that one or more plastic films may be used as the retardation film.

9. Liquid crystal display according to Claim 8, characterized in that a unidirectional plastic film, which is not stretched to saturation, is provided as the retardation film.

10. Liquid crystal display according to Claim 8, characterized in that the retardation film is a plastic film that is stretched bidirectionally.

11. Liquid crystal display according to one of Claims 8 through 10, characterized in that the retardation film is formed by a combination of one or more uniaxially positive and one or more uniaxially negative films.

12. Liquid crystal display according to one of the foregoing claims, characterized in that the retardation film is implemented in the form of a holographic element.

13. Liquid crystal display according to one of the foregoing claims, characterized in that the retardation film is implemented in the form of a liquid crystal polymer.

14. Liquid crystal display according to one of the foregoing claims, characterized in that the liquid crystal is oriented in different manners in the subpixels of a pixel so that the viewing angle ranges of the individual pixels supplement one another to form an essentially point-symmetric viewing angle range.

15. Liquid crystal display according to one of the foregoing claims, characterized in that the liquid crystal cell is a TN cell twisted by 80° to 100°.

16. Liquid crystal display according to one of the foregoing claims, characterized in that a photosensitive layer, in which the preferential direction of the liquid crystal molecules arranged thereon can be determined by exposure to light, can be used to orient the liquid crystal molecules on the substrate surface.

17. Liquid crystal display according to one of the foregoing claims, characterized in that the boundary areas between the subpixels are covered by a mask.

18. Liquid crystal display according to one of the foregoing claims, characterized in that each pixel has a switching element.

19. Liquid crystal display according to one of the foregoing claims, characterized in that each pixel has a thin-layer transistor and a reservoir capacitor, with at least one electrode of the reservoir capacitor being implemented using a conductive, non-transparent layer, which covers the boundary area between the subpixels.

## Abstract of the Disclosure

A liquid crystal display having a plurality of pixels, which includes a liquid crystal cell and polarizers (P1, P2) arranged on the top and bottom of the liquid crystal cell, is proposed, the liquid crystal cell having two substrates (DS, GS) with transparent electrodes and a liquid crystal sandwiched therebetween. To compensate for the dependence of the optical characteristics of the liquid crystal display such as, for example, transmission and contrast, on the viewing angle, each pixel is divided, according to the present invention, into at least two subpixels, in which the liquid crystal has different orientations and a biaxial retardation film (V1, V2) with different refraction indices  $n_e$ ,  $n_o$ ,  $n_z$  is arranged at least between a polarizer and the liquid crystal. The refraction index  $n_z$  occurs along an axis that is essentially parallel to the normal to the liquid crystal cell in the retardation film.



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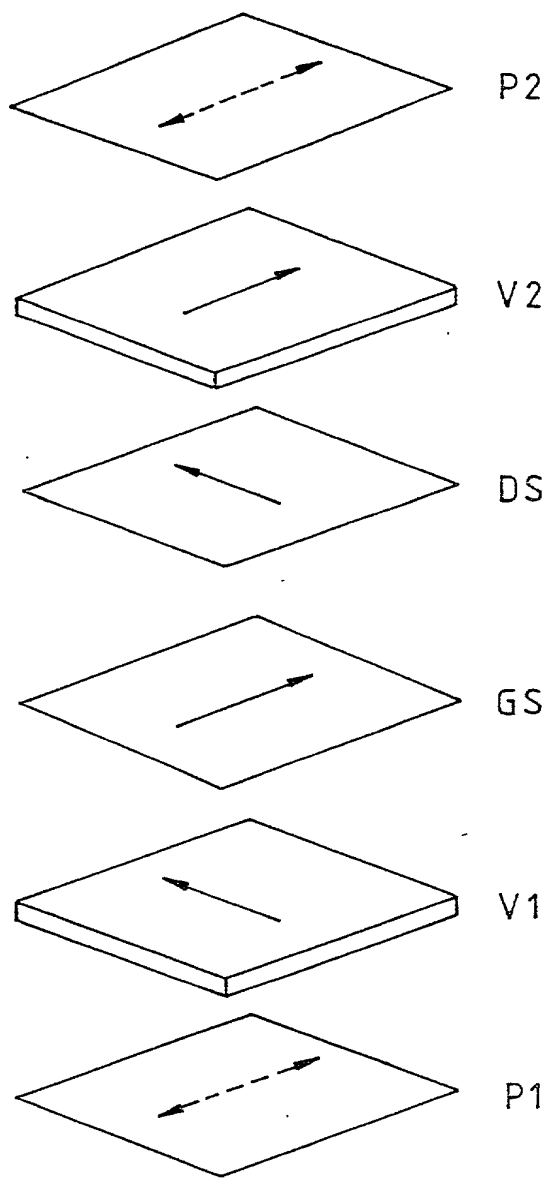


Fig. 1

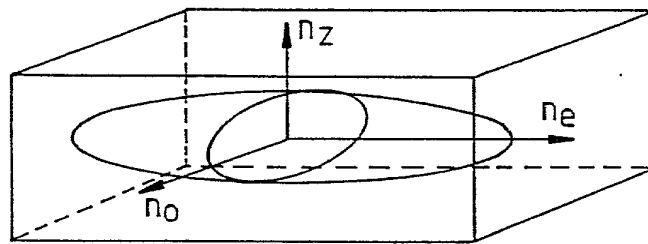


Fig. 2

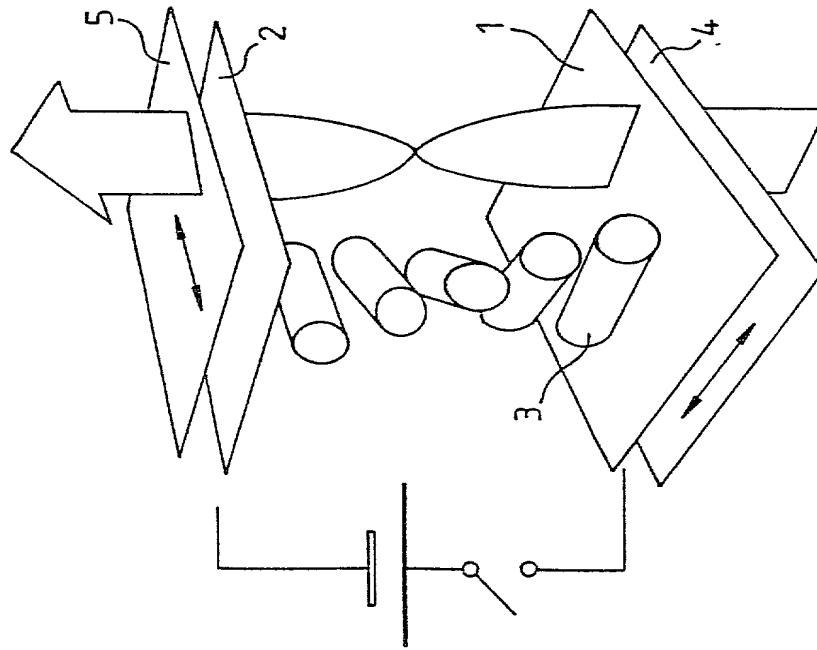


Fig. 3a

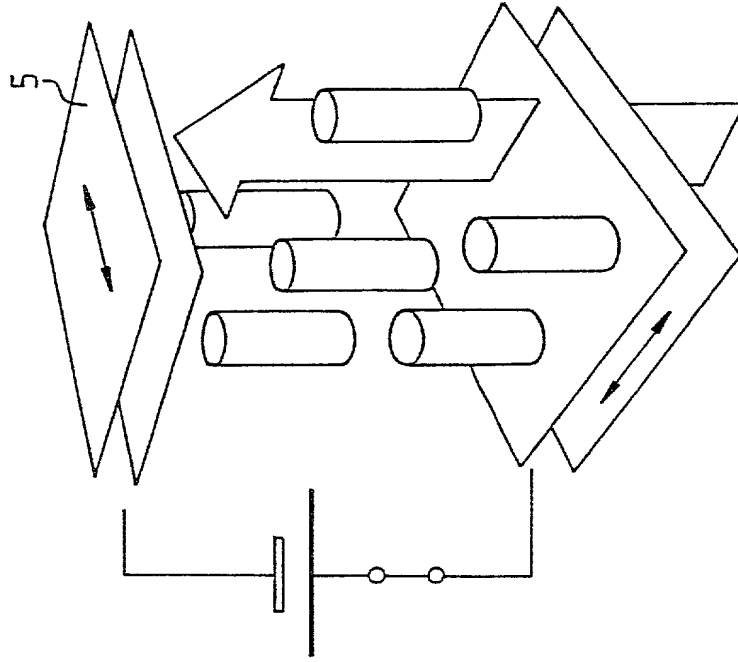


Fig. 3b

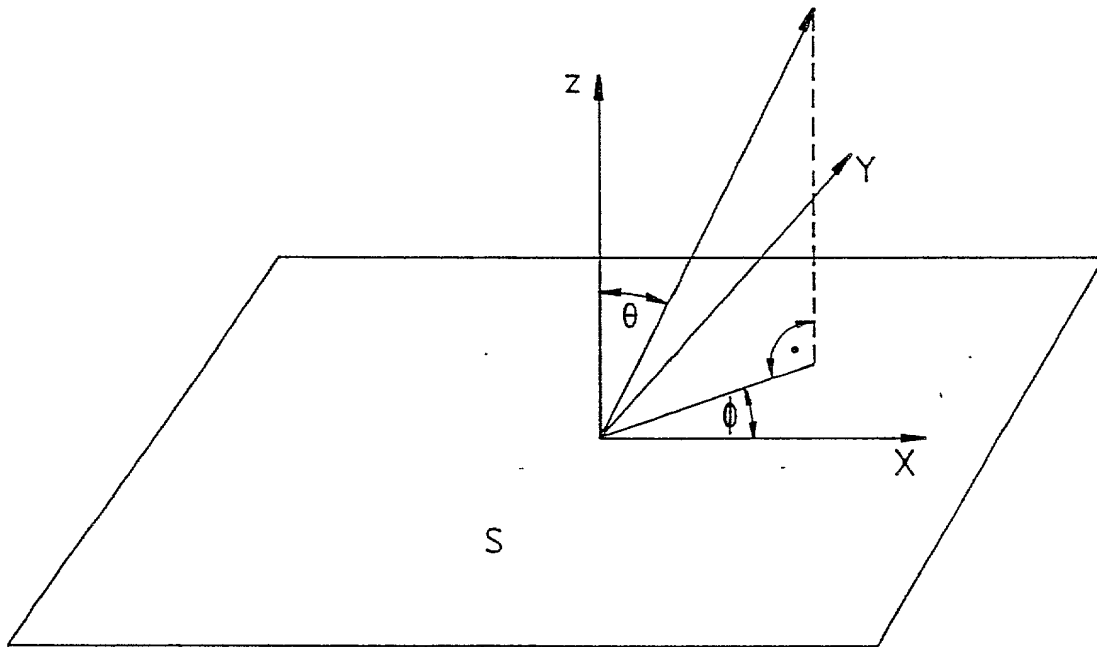
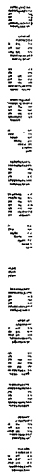


Fig. 4

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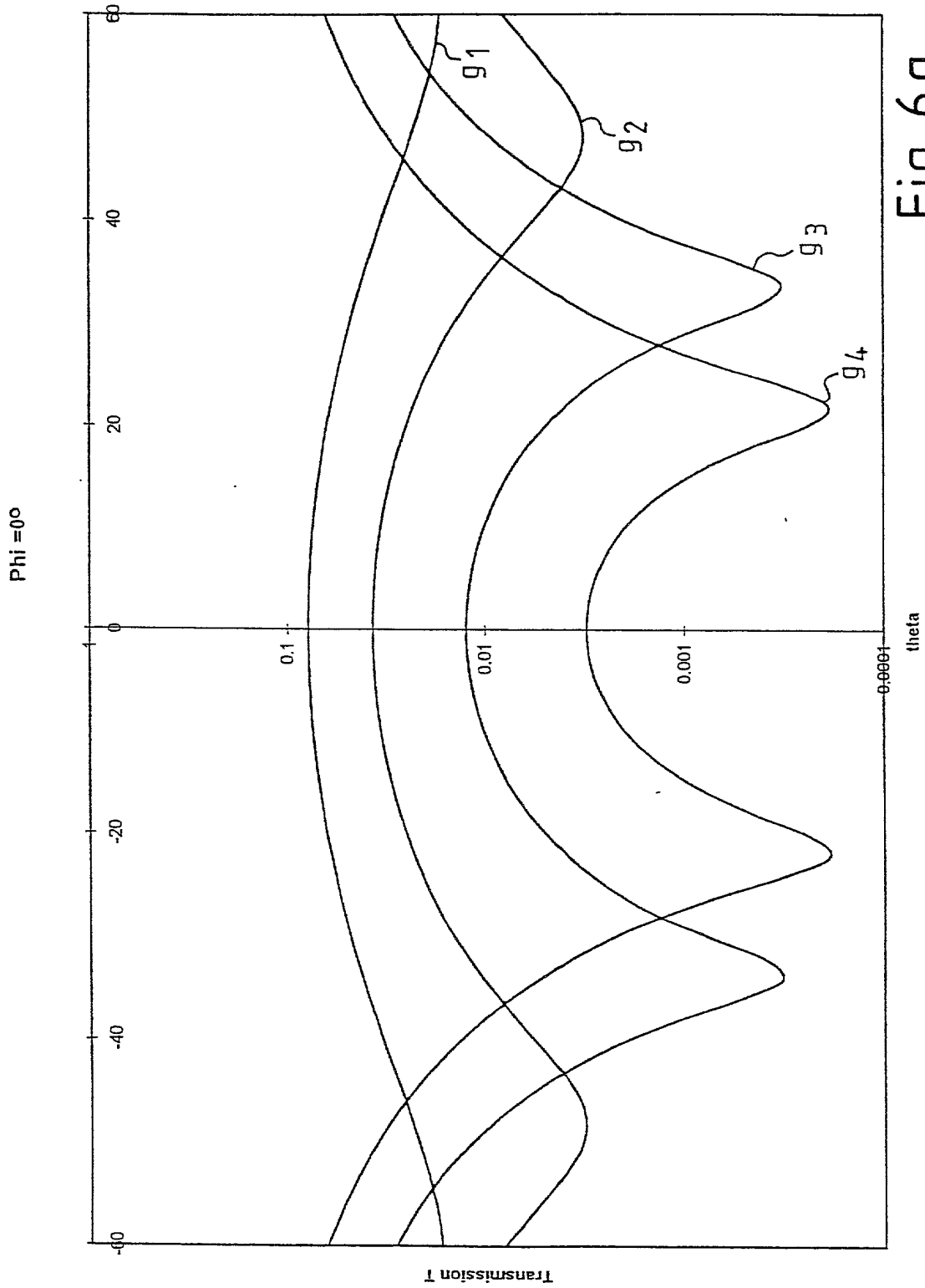


Fig. 6a

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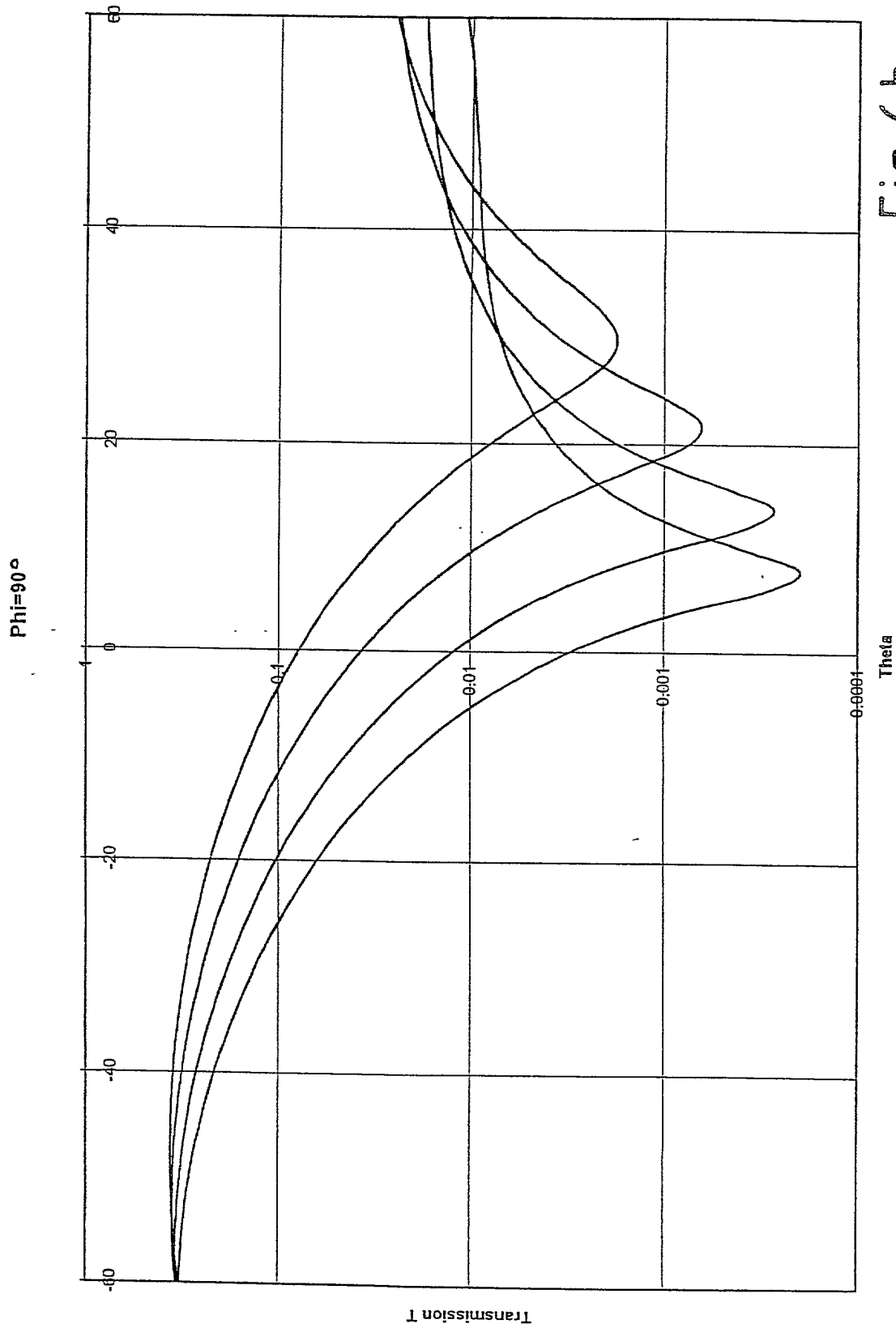


Fig. 6b

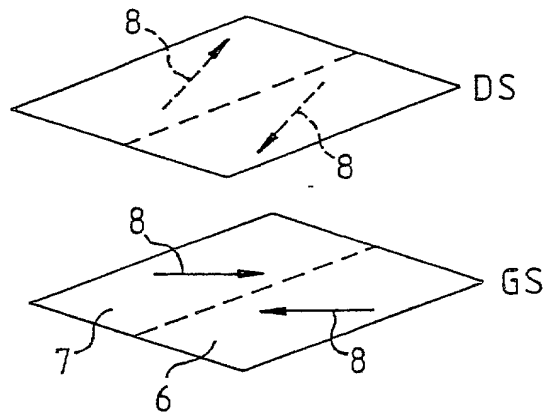


Fig. 7



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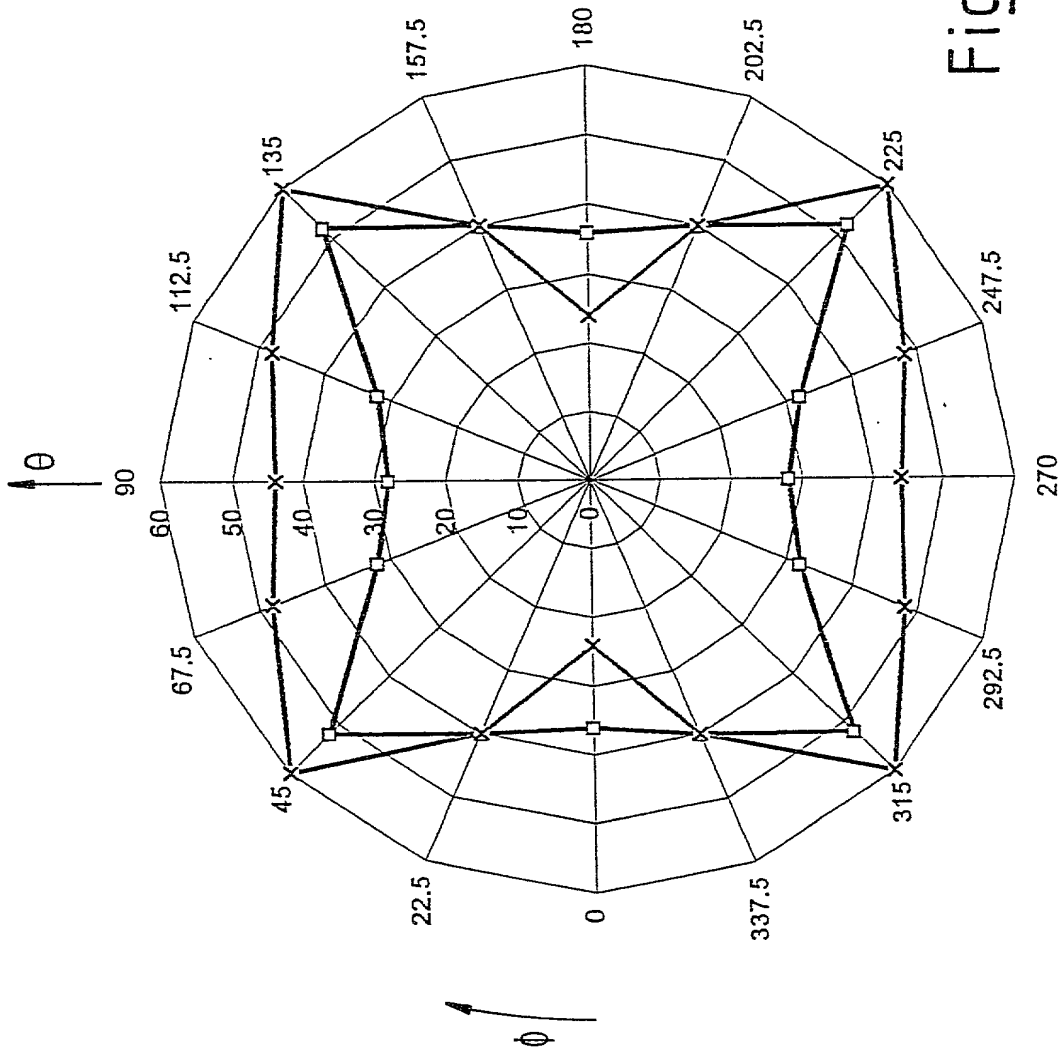


Fig. 8

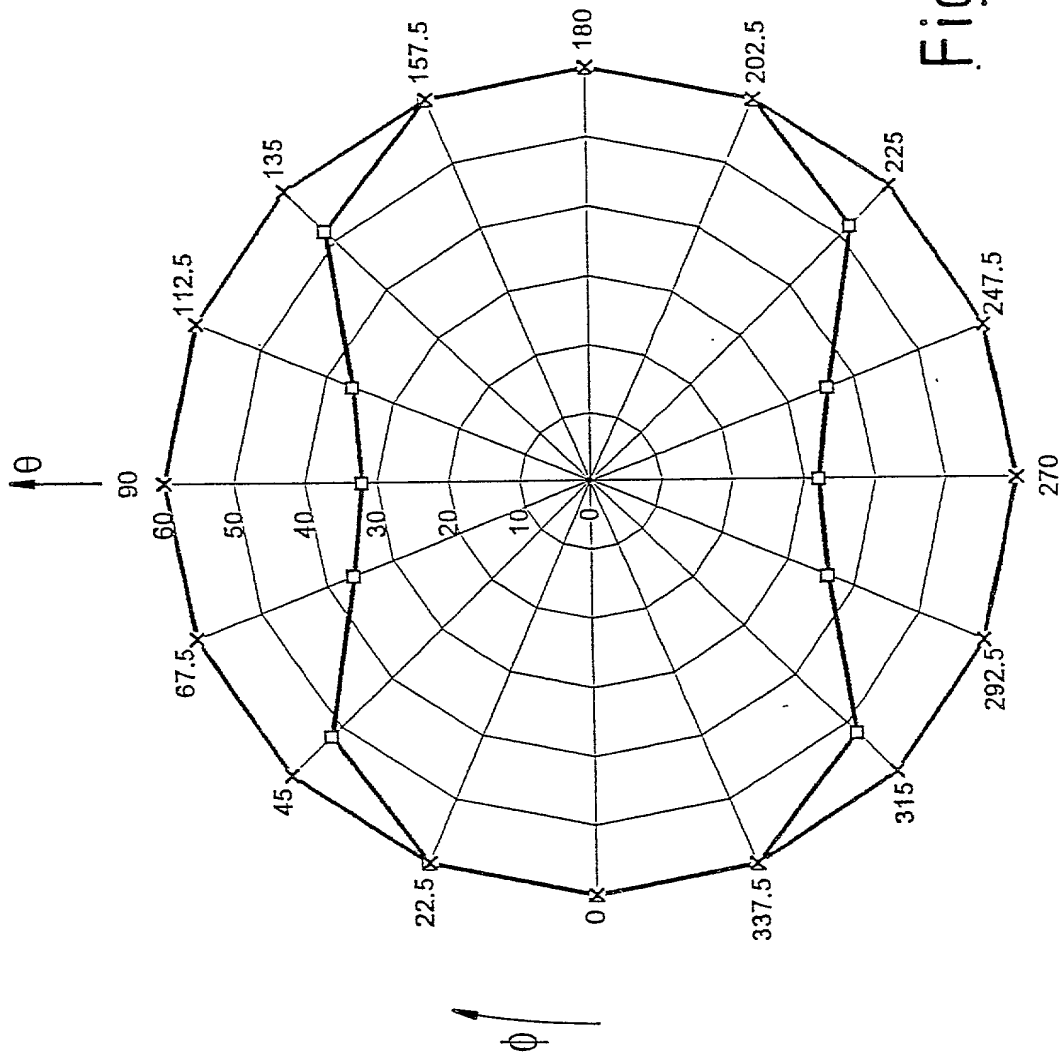


Fig. 9

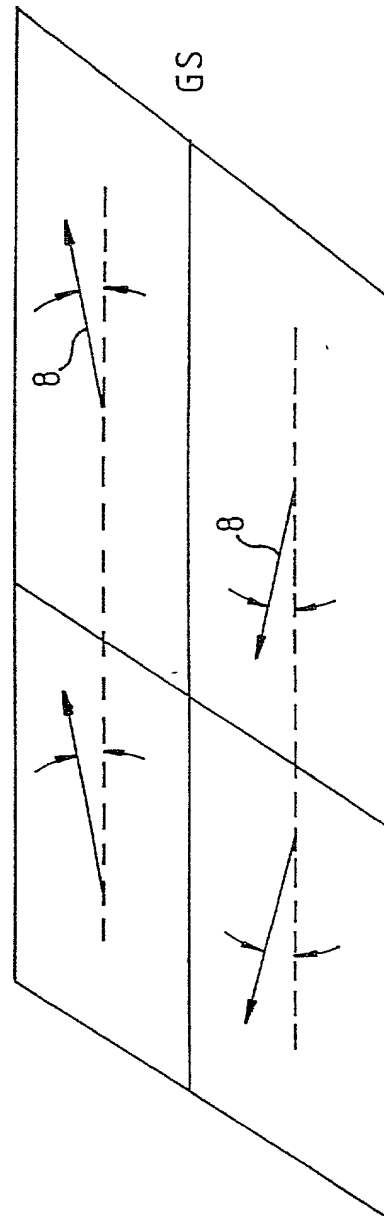
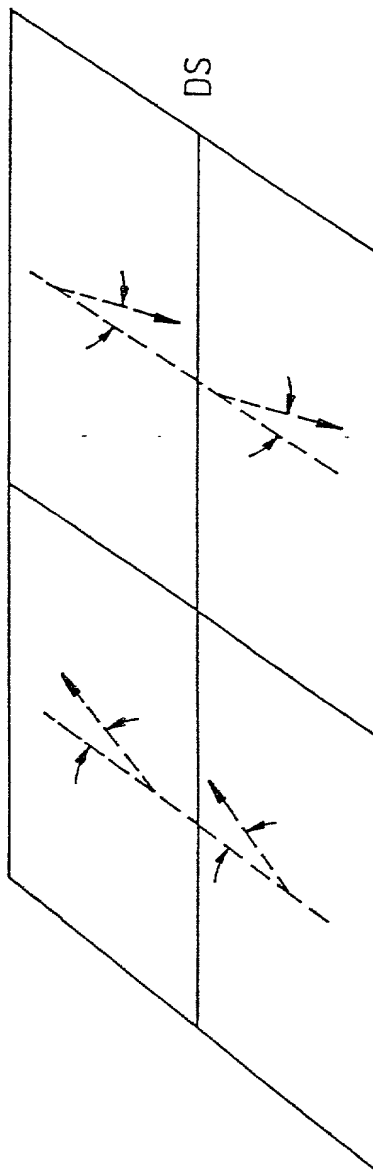
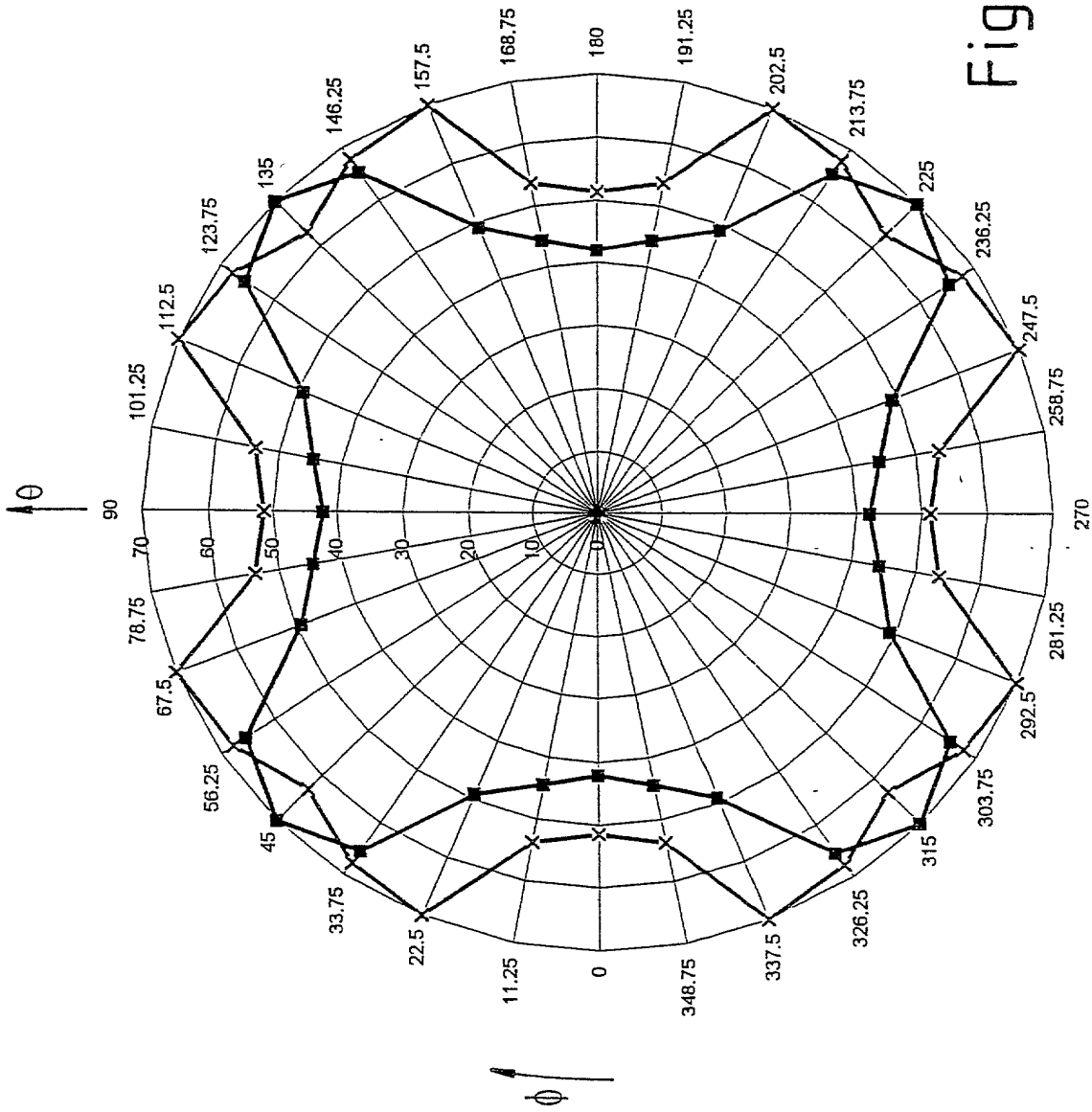


Fig.10

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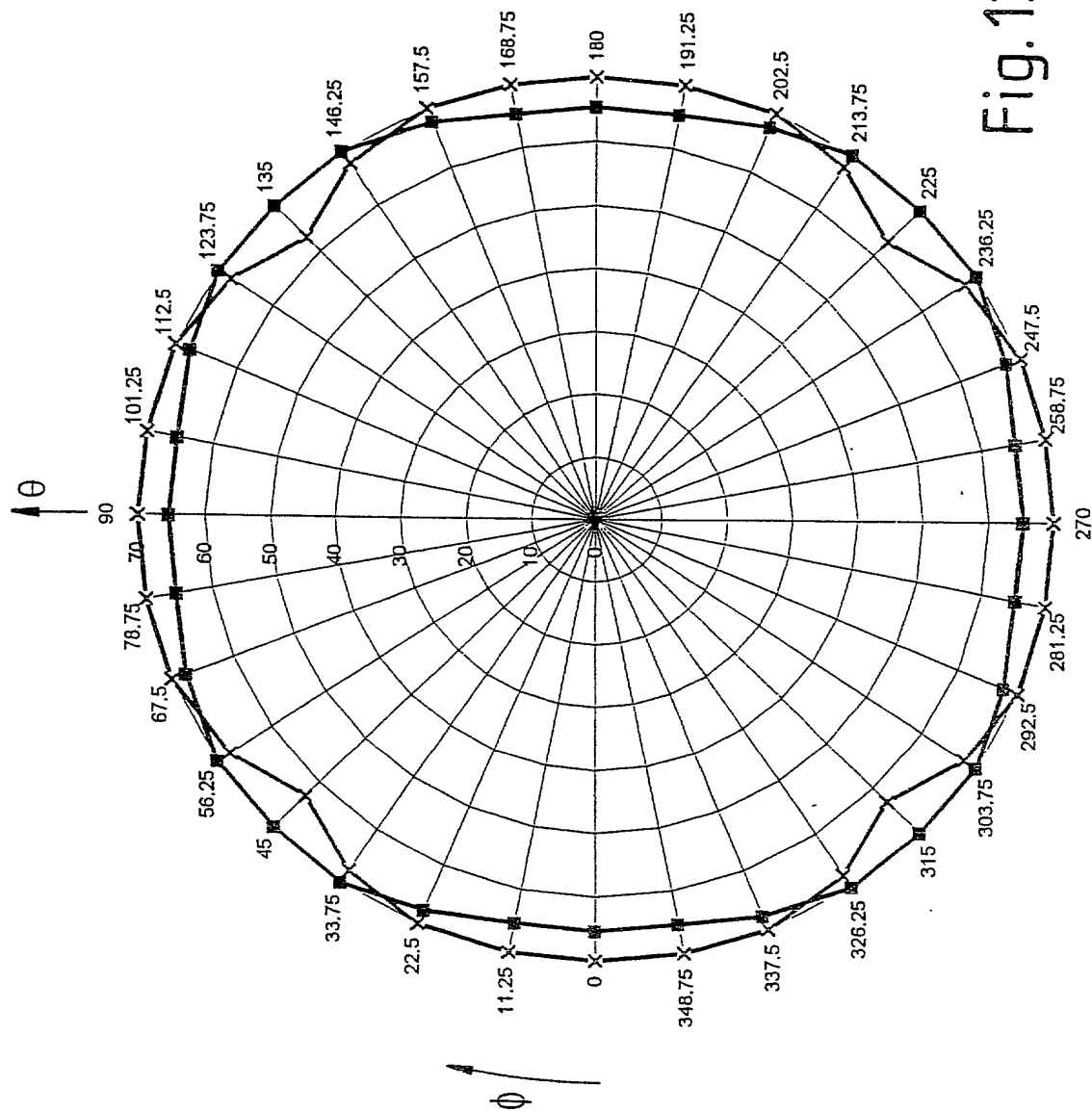


Fig.12

**DECLARATION AND POWER OF ATTORNEY**

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am an original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled **MULTIPIXEL LIQUID CRYSTAL DISPLAY**, for which an application for Letters Patent was filed as PCT International Application Number **PCT/DE98/00192** on January 22, 1998.


I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application(s) for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

**PRIOR FOREIGN APPLICATION(S)**

Number	Country filed	Day/month/year	Priority Claimed Under 35 USC 119
197 04 717.3	Fed. Rep. of Germany	7 February 1997	Yes



And I hereby appoint Richard L. Mayer (Reg. No. 22,490) and Gerard A. Messina (Reg. No. 35,952) my attorneys with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

Please address all communications regarding this application to:

~~KENYON & KENYON~~  
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New York, New York 10004

Please direct all telephone calls to Richard L. Mayer at (212) 425-7200.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful and false statements may jeopardize the validity of the application or any patent issued thereon.

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Inventor's Signature: \_\_\_\_\_

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Date: \_\_\_\_\_

~~August 2, 1999~~

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